METHOD AND APPARATUS FOR FLAW DETECTION IN SYNCHRONOUS SAMPLING (PRML) READ CHANNELS USING POST PROCESSED DIGITAL FILTERS

CROSS-REFERENCE TO RELATED APPLICATIONS

Priority is claimed from U.S. Provisional Patent Application Serial No. 60/203,088, filed May 9, 2000, entitled "ENHANCED FLAW DETECTION IN SYNCHRONOUS SAMPLING (PRML) READ CHANNELS USING POST PROCESSED DIGITAL FILTERING" and further identified as Attorney Docket No. 3123-354-PROV, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

The present invention relates to the detection of flaws in magnetic media using post processed digital filtering. In particular, the present invention relates to the detection of flaws in magnetic media in a synchronous sampling, partial response maximum likelihood (PRML) read channel using post processed digital filtering.

BACKGROUND OF THE INVENTION

Computer disk drives store information on magnetic disks. Typically, the information is stored on each disk in concentric tracks that are divided into servo sectors and data sectors. Information is written to or read from a disk by a transducer head, mounted on an actuator arm, capable of moving the transducer head radially over the disk. Accordingly, the movement of the actuator arm allows the transducer head to access different tracks. A disk is rotated by a spindle motor at a high speed, allowing the transducer head to access different sectors within each track on the disk. The transducer

head may include integrated read and write heads.

A typical computer disk drive **100** is illustrated in **Fig. 1**. The disk drive **100** includes a base **104** and magnetic disks **108** (only one of which is shown in **Fig. 1**). The magnetic disks **108** are interconnected to the base **104** by a spindle motor (not shown) mounted within or beneath the hub **112** such that the disks **108** can be rotated relative to the base **104**. Actuator arm assemblies **116** (only one of which is shown in **Fig. 1**) are interconnected to the base **104** by a bearing **120**. Actuator arm assemblies **116** each include a transducer head **124** at a first end, to address each of the surfaces of the magnetic disks **108**. The transducer heads **124** typically include read and write elements (not shown). A voice coil motor **128** pivots the actuator arm assemblies **116** about the bearing **120** to radially position the transducer heads **124** with respect to the magnetic disks **108**. By changing the radial position of the transducer heads **124** with respect to the magnetic disks **108**, the transducer heads **124** can access different tracks or cylinders **132** on the magnetic disks **108**. The voice coil motor **128** is operated by a controller **136** that is in turn operatively connected to a host computer (not shown). A channel **140** processes information read from the magnetic disks **108** by the transducer heads **124**.

With reference now to **Fig. 2**, a typical arrangement of data tracks **132** on a magnetic disk **108** is illustrated. Usually, the data tracks **132** are divided into data fields **204a-204h** with a servo sector **208a-208h** between one or more of the data fields **204a-204h**. Generally, the data fields **204a-204h** are used for storing data, while the servo sectors **208a-208h** are used for storing servo information, that is used to provide the transducer head **124** with positioning information. Typically, at least some of the

information contained in the servo sectors **208a-208h** is written during the servo track writing process, and the portions of the servo sectors **208a-208h** containing such information generally cannot be written to after the disk drive **100** is assembled. In particular, the servo sectors **208a-208h** provide the transducer heads **124** with information concerning their position over the magnetic disks **108**.

Although the magnetic disk **108** illustrated in **Figs. 1** and **2** is shown as having a relatively small number of data tracks **132**, data fields **204** and servo sectors **208**, it can be appreciated that a typical computer disk drive **100** contains a very large number of data tracks **132**, data fields **204** and servo or hard sectors **208**. For example, computer disk drives **100** having over 30,000 tracks per inch and 120 servo sectors are presently available.

In addition, alternate configurations of magnetic disks **108** are possible. For example, in a computer disk drive **100** having several magnetic disks **108**, a surface of one of the disks **108** may be dedicated to servo information, while the surfaces of the remaining disks **108** may be used exclusively to store data.

Data is generally stored on the disk **108** using patterns of magnetizations. For example, the magnetization of the disk **108** in a first direction may encode a digital 1, while a magnetization in a second direction may encode a digital 0. Accordingly, a transition in magnetization from one bit cell to a next bit cell signals a change from one character to another. A bit cell is the shortest length of a track **132** to which a particular magnetic polarity is written.

The magnetic disk **108** is generally formed from a film of magnetically hard

material deposited on a substrate. For example, the disk **108** may be formed by depositing a metal film on a rigid substrate. The thickness of the film must be closely controlled. Where, for example, the magnetic film is too thin, the magnetic flux produced by a magnetic transition in the thinned area will be less than the magnetic flux produced by a magnetic transition in an area of the disk having the specified film thickness. The magnetic flux density of a magnetic transition may also be affected by other defects on the disk **108**, such as scratches or pitting occurring during manufacture of the disk **108**, or during the assembly of the disk drive **100**.

In order to ensure the reliable storage and retrieval of user data from a disk drive **100**, manufacturers generally subject a disk drive **100** to numerous qualification tests before the disk drive **100** is delivered to an end user. Flaw scan testing is generally conducted in order to identify areas of the disk **108** that may not reliably encode user data. According to conventional methods of detecting flaws, a pattern of magnetic polarizations is written to those areas of the disk **108** to which write operations are allowed (*e.g.,* the data sectors) following assembly of the disk drive **100**. The magnetic polarization may be alternated every bit cell in the data sectors (*i.e.,* a 1T data pattern), or may be alternated after every i^{th} bit cell to produce an iT data pattern, where i is an integer number. For instance, the magnetic polarization may be alternated every two bit cells to produce a 2T data pattern. A 3T data pattern is produced if the data is written to the disk in a 111000111000 . . . pattern. In general, the higher the value of i the greater the signal amplitude, because of decreased intersymbol interference. This is true for iTs that result in data patterns having periods that occupy a length of track that is greater than the PW50

(*i.e.,* the isolated pulse width) of a signal derived from the disk. The PW50 is the distance between the points of intersection between an isolated pulse and a line indicating an amplitude that is equal to 50% of the maximum amplitude of the isolated pulse. Alternatively, a shorter period increases the likelihood of detecting a flawed area or the inability of a particular length of track **132** to produce a prescribed magnetic flux.

A conventional method for detecting flaws in a disk **108** is illustrated in **Fig. 3**. According to such a method, after the chosen pattern of magnetic polarizations has been written to the writable areas of the disk **108** by the write element of the transducer head **124** (step **300**), the read element of the transducer head **124** is used to read back the pattern of magnetic polarizations. In general, the channel **140** samples the varying voltage signal produced by the read element of the transducer head **124** from the pattern of magnetic polarizations written to the disk **108** as the track **132** passes beneath the transducer head **124**.

In a typical disk drive **100**, the channel **140** includes a partial response maximum likelihood (PRML) detector, which allows the accurate detection of patterns of magnetic polarizations even when the data is densely written on the disk **108**. In a partial response maximum likelihood type detector, the amplitude of a signal is sampled at regular time intervals. A code word symbolized by a set of pulses is then determined using a statistical maximum likelihood or Viterbi process. Accordingly, the targeted shape of a pulse is determinative in decoding a stored code word. The advantage of the PRML type detector is that the density of data, known as the user bit density (UBD), may be increased as compared to peak detection methods.

In general, peak detection methods must detect discrete bits of data. Thus, when pulses are densely packed such that the signal derived from a first bit is distorted, *e.g.*, by intersymbol interference, peak detection methods are incapable of reliably decoding pulses. In contrast, the PRML type detection method allows for the accurate detection of bits even when the pulse that would be generated by a bit in isolation is altered by its proximity to other bits (*i.e.*, is altered by intersymbol interference due to the linear superposition of the pulses). For instance, disk drives may accurately detect a series of bits when the isolated pulse width (PW50) of a signal contains 2.5 bits of information. Accordingly, a PRML detector allows for information to be recorded at increased user bit densities.

Flaw scanning techniques typically take advantage of the characteristics of the channel. For example, a 2T preamble is often used by the channel to synchronize sample times (*i.e.* phase) and to determine the amplitude of signals in the channel to allow the gain to be properly adjusted. When the phase and gain are properly adjusted, a 2T sampled waveform in the channel **140** produces a very distinctive pattern. In a conventional flaw scanning technique, the 2T data pattern is often used because of the high magnetic flux transitions, the relative low intersymbol interference and the unique sampled pattern it produces in the channel **140**.

With reference now to **Fig. 3**, according to conventional flaw detection techniques, a pattern of magnetic polarizations is written to the disk (step **300**). The channel **140** may then analyze the last n samples of the signal derived by the read element of the transducer head **124** from the disk **108**. In general, n-1 samples are taken (step **304**). Then, a next

sample (the n^{th} sample) is taken (step **308**). The channel **140** serially determines whether each of the previous n samples under consideration have an amplitude that is less than a threshold value (step **312**). If at least one of the last n samples has an amplitude that is more than the threshold value, the system returns to step **308** to take a next sample. Therefore, this conventional technique for detecting flaws is very susceptible to erroneously qualifying a series of bit cells where noise or some other disturbance may cause one or more samples to exceed the threshold. Accordingly, areas of the disk **108** that cannot reliably store user data may nonetheless be qualified to store data due to the effects of noise. Additionally, although disk drives **100** are typically provided with error correcting code that allows the disk drive **100** to tolerate at least some errors, the ability of such error correcting code to allow for the reliable storage of data in areas of the disk **108** containing flaws could be compromised. Similarly, this conventional method is susceptible to disqualifying a length of track **132** that does not contain errors in the presence of a sustained noise event.

In order to reduce the effects of noise, conventional flaw scanning is typically performed by making two or more passes over each surface of every disk **108** included in a disk drive **100**. Multiple flaw detection scans reduce the influence of soft errors such as may be caused by random noise, and thus increase the likelihood that flaws will be accurately detected. However, multiple flaw scans are undesirable, as they increase the time required to manufacture a hard disk drive **100** and, therefore, increase the cost of producing a hard disk drive **100** by decreasing manufacturing throughput. Furthermore, with the limitations of conventional flaw scanning techniques, it is difficult to detect with

high confidence the flaws that should be captured while rejecting false errors within a single pass. Therefore, conventional flaw scanning techniques require multiple passes if they are to detect flaws with high confidence.

For the above stated reasons, it would be desirable to provide a method and an apparatus capable of detecting flaws in a disk **108** with improved confidence. In addition, it would be advantageous to provide a method and an apparatus for detecting flaws on a disk **108** that can provide the required confidence in as few a number of scans as possible, and preferably in one pass. It would also be desirable to provide a method and an apparatus that can detect flaws on a disk with a high degree of statistical confidence, without the detection of false errors. Furthermore, it would be desirable to provide both a method and an apparatus for the detection of flaws on a disk drive **100** that are reliable in operation and that are inexpensive to implement.

SUMMARY OF THE INVENTION

In accordance with the present invention, both a method and an apparatus for detecting flaws in disks of a hard disk drive are provided. The present invention generally allows flaws in a disk to be detected with a much higher degree of statistical confidence, thus allowing fewer passes than with conventional techniques. Furthermore, the present invention produces an overall media qualification that is at least as good or better than the conventional method and does so in less time.

In accordance with one embodiment of the present invention, a method and an apparatus are provided in which information written to a disk of a hard disk drive is read from the disk. The information may be written on the disk in an iT data pattern where i is

an integer number. A read signal derived from the information written to the disk is periodically sampled. All or a subset of the samples derived from a discrete portion of the disk are then used to derive a value. The derived value is then compared to a threshold value. If the derived value is less than the threshold value, a flag is generated to signal the detection of a flaw.

In accordance with a further embodiment of the present invention, the information written to the disk is written in an iT pattern so as to produce a periodic signal in the transducer head of the disk drive. This periodic signal may in turn encode a repeated pattern of data.

In accordance with still another embodiment of the present invention, data is written on the disk such that the magnetic polarity of a bit cell signals a 1 or alternatively a 0. A test pattern of data is then written on the disk. A method or apparatus in accordance with the present invention may then consider those samples of the signal taken at times corresponding to peaks or near peak samples in the readback signal. The samples under consideration may be used to derive a value for comparison with a threshold value. Based upon the comparison with the threshold value, a signal may or may not be generated to indicate the presence of a defect.

According to one embodiment of the present invention, the derived value for comparison with a threshold amount is obtained by passing a selected number of samples through a digital band pass filter. This has the result of suppressing the effects of noise on the sampled signal. Accordingly, in an embodiment in which the test data is written in a 2T data pattern, the derived value is obtained by passing n samples through a digital filter

that in delay operator notation is given by the expression $1 - D^2 + D^4 - D^6 \ldots \pm D^{2n}$, where n is equal to the total number of samples within the window. According to still another embodiment in which the test data is written in a 3T data pattern, the derived value is obtained by passing n samples through a digital filter that in delay operator notation is given by the expression $1 + D - D^3 - D^4 + D^6 + D^7 \ldots [-/+ D^{n-1} -/+ D^n]$.

In accordance with yet another embodiment of the present invention, a value for comparison with a threshold value is derived by calculating a sum of the absolute value of a selected number of the samples under consideration. According to another embodiment of the present invention, the absolute value of all or a selected plurality of the n samples under consideration are integrated. According to still another embodiment of the present invention, the value for comparison with a threshold amount is derived by summing together the magnitudes of m of the n samples under consideration and dividing by m to obtain an average sampled value, where m is an integer number.

In accordance with a further embodiment of the present invention, an optimal sample level is subtracted from the absolute value of each of m samples to obtain an error value. The error values obtained for each of the m samples may then be summed, averaged or integrated. The result may then be compared to a threshold value and a defect indicated if the comparison is not favorable.

In accordance with still another embodiment of the apparatus of the present invention, the samples are fed into a Finite Impulse Response filter (FIR) or continuous shift register of samples that are summed into a value on every i^{th} clock cycle from all or a selected plurality of the n samples under consideration. In addition, a memory register for

storing a threshold value is provided. The derived summation or value from the FIR filter is compared to the threshold value register at the input of a comparator. The comparator generates a signal indicating a detected defect if the sum of the samples is less than the threshold amount.

Additional advantages of the present invention will become readily apparent from the following discussion, particularly when taken together with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a diagrammatic representation of a top view of a conventional computer disk drive, with the cover removed;

Fig. 2 is a diagrammatic representation of a magnetic storage disk;

Fig. 3 is a functional flow diagram of the operation of a conventional system for detecting flaws on a disk;

Fig. 4A depicts magnetic polarizations in a cross section of track contained on a disk;

Fig. 4B depicts the magnetization of the cross section of track illustrated in **Fig. 4A**;

Fig. 4C illustrates an example voltage potential produced in the channel as a result of the pattern of magnetization depicted in **Fig. 4B**;

Fig. 5 depicts a typical signal produced in a channel in response to passing the transducer head through a pattern of magnetic flux, in which the signal is influenced by the presence of intersymbol interference and a flaw;

Fig. 6 is a functional flow diagram illustrating the operation of a system for the

detection of flaws on a disk in accordance with the present invention; and

Fig. 7 is a functional block diagram of hardware configured in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

With reference now to **Fig. 4A**, a portion of a track **132** to which a repeated pattern of data has been written is schematically illustrated. The section of track **132** illustrated in **Fig. 4A** can be seen to contain a number of bit cells **400a-400i**. An arrow in a bit cell **400** indicates the magnetic polarity of the bit cell. If the magnetization of a bit cell in a given direction is a 1 and the magnetization of a bit cell in the opposite direction is a 0, it can be seen that the pattern of data produced by the pattern of magnetic transitions illustrated in **Fig. 4A** is such that each character is alternately repeated for two bit cells. That is, the pattern of bits is 1,1,0,0,1,1,0,0 . . . as shown in **Fig. 4A**. This is known as a 2T data pattern. In a 3T pattern, the pattern of bits is 1,1,1,0,0,0,1,1,1,0,0,0 . . . . In general, the pattern of magnetic transitions illustrated in **Fig. 4A** may be described as an iT data pattern, where i is an integer number.

With reference now to **Fig. 4B**, a pattern of magnetic polarities corresponding to the pattern of magnetization shown in **Fig. 4A** is illustrated. As shown in **Fig. 4B**, a pattern of magnetic polarities written to a track **132** effectively forms a series of magnets **404** in the track **132**. As can be appreciated, at the boundaries of the magnets **404**, which correspond to boundaries between bit cells **400** containing opposite magnetic polarities, the lines of magnetic flux produced by the magnets **404** will be normal to the surface of the disk **108** in the vicinity of the disk surface. In addition, the direction of the magnetic

flux will be substantially parallel to the surface of the disk **108** in areas away from magnetic transitions in a longitudinal recording scheme. It should be noted that the present invention is equally applicable to a perpendicular recording scheme. As can also be appreciated, a transducer head **124** following a track **132** in close proximity to the surface of the disk **108** can sense these changes in magnetic flux. As will be understood by those of ordinary skill in the art, the changes in magnetic flux can be used to produce a voltage or a change in resistance in a read element of the transducer head **124**.

With reference now to **Fig. 4C**, a waveform **408** produced in the channel **140** as the transducer head **124** passes through the magnetic flux produced by the magnetization illustrated in **Fig. 4A** is depicted. In general, the waveform **408** is expressed in the channel **140** as a voltage or current signal.

By comparing **Figs. 4A** and **4C**, it can be appreciated that peaks **412** in the waveform **412** occur periodically. In particular, the peaks **412** correspond to magnetic transitions written on the track **132**. Because the amplitude at the zero crossings is expected to be zero, such samples can be discarded. Discarding samples taken at times corresponding to zero crossings improves the signal to noise ratio of an asynchronously sampled signal, as the amplitude of the retained samples, which are expected to be peak (or near peak) values, will be relatively large compared to the near zero samples, where noise can greatly affect the relative sample amplitude.

The waveform **408** illustrated in **Fig. 4C** is affected by intersymbol interference. That is, the illustrated waveform **408** is produced in connection with magnetic transitions within the track **132** that are close enough together to cause the magnetic polarizations

written to the track **132** to affect the flux patterns produced by adjacent magnetic polarizations. In general, as bit cells **400** become smaller, the pattern of magnetic flux produced by magnetic transitions between the bit cells **400** become increasingly subject to intersymbol interference (*i.e.,* as the user bit density becomes greater than 1.0).

A waveform **500**, such as may be produced by the pattern of magnetic transitions illustrated in **Fig. 4A** in a typical disk drive **100** in which the waveform **500** is affected by intersymbol interference, is illustrated in **Fig. 5**. It can be appreciated that any disturbance of the system, such as may be produced by noise, can greatly affect how the waveform **500** is interpreted. Therefore, it is useful to increase the signal to noise ratio in such systems. As mentioned above, it is possible to increase the signal to noise ratio by using a 2T or greater pattern and by considering only those samples taken at times that a significant non-zero value (*i.e.* a peak or near peak value) is expected.

With continued reference to **Fig. 5**, it can be seen that five peaks **508a-508e** of the example waveform **500** have an amplitude that is diminished relative to the other peaks. This diminished amplitude may be the result of noise and/or a flaw in the disk **108**. However, it is unlikely that noise would cause five peaks in a row to be as deeply attenuated as those illustrated in **Fig. 5**. Therefore, the attenuation is likely due to a flaw in the disk **108**. Accordingly, this attenuation is preferably detected by the channel **140** and reported to the controller **136** of the disk drive **100**. However, such a defect may not be detected using conventional flaw detection schemes. For example, a greater number of attenuated peaks in a row may be required. In addition, conventional techniques for detecting flaws in a disk drive **100** are less sensitive to slight variations in amplitude loss.

Therefore, if the waveform **500** illustrated in **Fig. 5** contains a particularly deep flaw, such as illustrated by first alternate peak **512**, a conventional flaw detection system will not take into consideration the relatively large attenuation of the first alternate peak **512**. Furthermore, a conventional flaw detection system may fail to signal the detection of a flaw if even one of the peaks **508** in a series has an amplitude greater than the threshold value. Therefore, even in connection with a flaw detection system that would detect a flaw after a series of five diminished peaks **508a-e**, if even one of the peaks has an amplitude greater than the threshold (*e.g.,* second alternate peak **516**), no flaw will be detected.

According to the present invention, a waveform or signal (*e.g.,* **412** or **500**) produced by reading a pattern of magnetic transitions is analyzed using a peak filtering window method. In general, a selected set, or window, of samples is considered as a group in order to reduce the effects of noise on the sampled signal. In addition, the signal to noise ratio may be increased by considering only samples taken at times corresponding to magnetic transitions (*i.e.* by considering only peak or near peak samples). According to one embodiment of the present invention, the magnitude or absolute value of the amplitude of m of the previous n samples under consideration are summed, or are integrated or averaged over m, to provide a value that can be compared to a selected threshold amount. Accordingly, the present invention effectively passes the samples under consideration through a band pass filter, reducing the noise bandwidth present in the signal by $\sqrt{1/m}$ where m is the number of samples in the window that are considered. By reducing the noise in the signal, the signal to noise ratio is improved, and flaws in the disk

108 can be more accurately distinguished from noise. Accordingly, a more efficient technique for detecting flaws in a disk drive **100** is provided.

In accordance with another embodiment of the present invention, the previous n samples of a signal produced by an iT data pattern are passed through a filter that considers only those samples corresponding to expected peaks or near peaks in the signal derived from the data encoded on the disk **108**. In delay operator notation, the filter in accordance with this embodiment of the present invention for use in connection with a 2T data pattern is given by the expression $1 - D^2 + D^4 - D^6 \ldots \pm D^{2+n}$, where n is equal to the total number of samples within the window. A filter in accordance with the present invention for use in connection with a 3T data pattern is given by the expression $1 + D - D^3 - D^4 + D^6 + D^7 \ldots [-/+ D^{n-1} -/+ D^n]$. As can be appreciated, these filters consider every sample corresponding to an expected peak or near peak sample in the signal derived from the written pattern, and changes the sign of the sampled values so that they are all the same. As can also be appreciated, a digital filter that passes only the most significant samples (*i.e.* samples that are expected to contain peak or near peak values) and discards the other samples can be provided for any pattern of data. A significant sample may be understood to be any signal having an amplitude that is greater than 50% of the amplitude of an isolated pulse. As will be appreciated by those of ordinary skill in the art, the partial response of the channel's detector and the data pattern chosen for flaw scan detection will affect what samples are considered significant. The sum resulting from the application of such a filter may then be compared to an acceptable or a threshold value.

As an example, if the encoded data has a 2T pattern, and m is equal to 5, the

digital filter applied to the samples is given by the expression $1 - D^2 + D^4 - D^6 + D^8$. As a further example, if the samples can be quantized into integer values ranging from -30 to +30, and the optimal sample value is 16 defined by the partial response of the channel, the sum obtained by the digital filter should be m x 16 = 80 where m is equal to 5.

According to another embodiment of the present invention, the magnitude or absolute value of each of the previous significant samples are summed together. The resulting positive value is then compared to a selected acceptable or threshold value. The controller **136** is signaled that a defect has been detected if the sum of the samples are found to be unacceptable (*e.g.*, not greater than the acceptable value).

According to still another embodiment of the present invention, the sum resulting from the addition of the magnitude or absolute value of each of the previous m significant samples is divided by m to obtain an average sampled value. The resulting average value, which will again be a positive number, may then be compared to a selected acceptable or threshold value. A defect is signaled to the controller **136** if the average value is unacceptable (*e.g.*, is less than the threshold amount).

According to still another embodiment of the present invention, the magnitude or absolute value of each of the previous m significant samples are integrated. The result of the integration is then compared to a selected acceptable or threshold value. If the integrated value is less than the selected acceptable value, a defect is indicated and the controller **136** is signaled accordingly.

With reference now to **Fig. 6**, the operation of an embodiment of the present invention is illustrated. Initially, at step **600**, a pattern of magnetizations is written to the

disk **108**. For example, in a magnetic digital system, the magnetization of a bit cell in a first direction may encode a value 1, and the magnetization of a bit cell in second direction may encode a value 0.

A repeated pattern of magnetization and therefore of encoded data, is preferably written to the disk **108** to simplify the determination of whether a bit cell produces a signal of the expected amplitude in the channel **140**. In a preferred embodiment of the present invention, the pattern of encoded information is written to all areas of a disk **108** that can be written to after the disk drive **100** has been assembled, including the data sectors **204** and all writable areas of the servo sectors **208**. As is also noted above, the data may be written in an iT pattern, where i is an integer number, in which the direction of magnetic polarization is alternated every i bit cells. Although improvements in the signal to noise ratio may generally be realized by increasing the value of i (at least until the effective channel bit density is equal to one) it should be appreciated that the present invention is operable with any pattern of encoded data, including a 1T pattern.

Next, samples are taken from the signal derived from the transitions written to the disk. The signal or waveform is sampled once for every bit cell **400** in the length of track **132** in the window or length of track under consideration. As noted above, only the significant samples, such as the peak samples, which may include near peak samples, are preferably considered in order to increase the signal to noise ratio in the flaw detection system. Therefore, at step **604** m - 1 of the samples are considered. That is, of the previous n samples taken, the m - 1 samples corresponding to significant samples in the waveform are considered. At step **608**, a next, or m^{th}, peak sample is taken. The

magnitudes or absolute value of the amplitudes of each of the m peak samples are summed (step **612**). Alternatively, the sign of the samples may be changed so that they are all the same, and the sum of the samples may then be calculated. As still another alternative, a difference between an absolute value of each of said m values and an optional value may be calculated, and the resulting differences may be added to obtain a sum.

At step **616**, the sum derived from the previous m peak samples is compared to the selected threshold value (*i.e.*, the acceptable value). If the sum is determined to be less than the selected threshold value, the sum is unacceptable, and the controller **136** is signaled that a defect has been detected (step **620**). Alternatively, the sum may be found to be unacceptable and the controller **136** may be signaled that a defect has been detected if the sum is not greater than the threshold value. The system then returns to step **608**.

If the sum of the previous m peak samples is determined to be acceptable, the system returns to step **608**, at which point a next peak sample is taken. Accordingly, it can be appreciated that a moving window that includes the previous m peak samples is considered when determining whether to signal the controller **136** that a flaw requiring attention has been detected. That is, the previous m samples are considered on a first in first out (FIFO) basis. In addition, it can be appreciated that the effects of noise are diminished by considering a value derived from peak and near peak samples. That is, according to the present invention, the sample signal is subject to a band pass filter.

Although in a preferred embodiment, the m samples considered correspond to the m significant samples, it should be appreciated that, according to the present invention, m may be equal to n, the total number of samples within the window.

The selection of a threshold value will depend on the partial response of the disk drive's **100** channel. For example, where the signal derived from the disk **108** may be quantized into integer values ranging from -30 to +30, and the magnitude of the optimal peak signal amplitude is 16, a threshold amount of less than 16 would be selected for comparison with an average of the absolute value of each of the previous m samples. Of course, where the sum or integrated value of the absolute value of the m samples are to be compared to a threshold amount, the threshold value would be less than m x 16. According to one embodiment of the present invention, the threshold value to detect defects is about 50-90% of the accumulated value of the expected samples. The threshold value depends on the size of the defect to be detected.

With reference now to **Fig. 7**, hardware components in accordance with an embodiment of the present invention are depicted in functional block diagram form. A shift register **700** is provided for temporarily storing the previous m significant or peak values from the window of n samples. The provided samples may be stored as absolute values (*i.e.*, they may represent a magnitude of the value, without reference to whether the value is positive or negative). The values stored in the shift register **700** are continually fed into a summing block **704**. The output from the summing block **704** is continually clocked to a comparator **708**. Also provided to the comparator **708** is a threshold value stored in memory **712**. The output of the comparator **708** may comprise a signal provided to the controller **136** to indicate the detection of a defect if the sum of the previous m peak samples is unacceptable. For example, according to one embodiment of the present invention, the controller **136** is signaled if the sum of the m samples is less than the

threshold value.

Although the hardware components that may comprise the present invention are illustrated as discrete components in **Fig. 7**, the example of **Fig. 7** is intended to be non-limiting. Furthermore, it should be appreciated that the present invention may be implemented as software code running on a microprocessor. In addition, when used in connection with a hard disk drive **100**, the present invention may be implemented as firmware code running in the controller **136** and/or channel **140** of the hard disk drive **100**.

Furthermore, although the present invention has been described in connection with examples concerning magnetic disk drives, the present invention is not so limited. In particular, the present invention may be applied in connection with any memory device. For instance, the present invention may be applied in connection with optical, tape, or three dimensional storage devices.

The foregoing discussion of the invention has been presented for purposes of illustration and description. Further, the description is not intended to limit the invention to the form disclosed herein. Consequently, variations and modifications commensurate with the above teachings, within the skill and knowledge of the relevant art, are within the scope of the present invention. The embodiments described hereinabove are further intended to explain the best mode presently known of practicing the invention and to enable others skilled in the art to utilize the invention in such or in other embodiments and with various modifications required by their particular application or use of the invention. It is intended that the appended claims be construed to include the alternative embodiments to the extent permitted by the prior art.